White Paper

The Role of Engineering Simulation in the Continued Evolution of Unmanned Aircraft Systems

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Across all domains (land, sea and air), the use of unmanned aircraft systems (UASs) has shown explosive growth and, as their value continues to be demonstrated, this growth shows no sign of slowing. However, the UAS industry must address a number of key challenges if it is to satisfy the future roadmap for UAS development and deployment outlined by its major client, the U.S. Department of Defense (DoD).

These challenges include:

- Transition from mission-specific platforms to a reduced number of common platforms that can serve multiple missions across and in conjunction with different domains
- Increased platform capability including all-weather flight, payload weight, speed, endurance (even ultra-endurance), point to point, survivability and refueling
- Increased payload capability that empowers advanced sensing, autonomy, swarming and teaming, weaponization, electronic warfare
- Reduced forward footprint to lower the manpower burden in the theater of operation
- Development of effective micro-UASs for rapid tactical deployment
- Expanded missions including strike, cargo and medical evacuation
- Adaptability in a fiscally constrained environment

This white paper explores the role and value of engineering simulation to the UAS community as it seeks to address these challenges. It highlights some of the project- and organizational-level implications of using engineering simulation.

The fit between the demonstrated benefits of engineering simulation and the UAS industry drivers is so strong that those not using engineering simulation today are not likely to be tomorrow's UAS designers and suppliers.

"Today, engineering simulation plays a fundamental role in the development of the leading UAS platforms in areas such as aerodynamics, structural performance, electronic systems, propulsion and thermal management. As UASs continue to develop, for example with increased autonomy, engineering simulation will become ever more critical due to the need for more detailed understanding of the aerodynamic and integrated system-level performance."

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The Evolving Role of UAS

Unmanned aircraft systems are a proven and invaluable asset for militaries around the world, and their use has seen tremendous growth in recent years. By its very nature, an unmanned aircraft projects power without projecting vulnerability.

UASs also have demonstrated value in civilian operations such as border patrol and disaster assistance. An example of the latter is the U.S. Air Force's decision to deploy a Northrop Grumman Global Hawk to Japan in the aftermath of the 2011 earthquake, tsunami and nuclear disaster.

In 2010, the U.S. DoD's UAS program logged over 550,000 flight hours, not including mini/micro tactical UAS that are typically hand-launched. To place the growth of UAS use in context, it took roughly the 10 years from 1995 to 2005 for the DoD to log its first 250,000 UAS flight hours [1]. In 2011, the projected DoD spend on UAS procurement along with research, development, test and evaluation (RDT&E) is $6 billion [2].

UASs are one component of the wider unmanned systems category that includes unmanned ground vehicles and unmanned maritime vehicles. This paper focuses exclusively on the UAS; the sidebar identifies the general classification of these systems.

UAS Classifications

The DOD classifies UASs into a number of groups [3] that include:

Group 1: Mini and Micro Tactical UAS — These include hand-launched, man-portable systems with a gross takeoff weight of less than 20 pounds, short endurance, operating at less than 1,200 feet and with airspeed of less than 100 knots. Group 1 includes the RQ-11 Raven, Puma and Wasp. These are typically used for intelligence, surveillance and reconnaissance (ISR) as well as reconnaissance, surveillance and target acquisition (RSTA).

Group 2: Small Tactical UAS — These medium-sized, catapult-launched mobile systems have a gross takeoff weight of between 21 and 55 pounds. They operate at less than 3,500 feet with airspeed less than 250 knots. The ScanEagle is one example, typically employed in ISR, RSTA and force protection.

Group 3: Tactical UAS — Larger than groups 1 and 2 and requiring more ground-based logistics, these systems have a gross takeoff weight of less than 1,320 pounds; they operate up to 18,000 feet above mean sea level with airspeed less than 250 knots. These UASs can extend the capabilities of groups 1 and 2 to include battle damage assessment. Examples include the RQ-7 Shadow and RQ-21.

Group 4: Persistent UAS — With a gross takeoff weight exceeding 1,320 pounds and operating at less than 18,000 feet above sea level at a wide range of airspeeds, a persistent UAS typically requires some form of runway. These systems can offer strike capability. They include the Hunter, Hummingbird, Fire Scout, Warrior, Gray Eagle and Predator.

Group 5: Long-Endurance UAS — Operating above 18,000 feet and with a gross takeoff weight exceeding 1,320 pounds, these are the largest UASs available today. Examples include the MQ-9 Reaper and RQ-4 Global Hawk. These systems can fulfill a wide range of roles.

Until 2007, the U.S. Air Force, Army and Navy each published and updated independent unmanned systems technology roadmaps for their individual services. This splintered approach was evidence of the immature nature of unmanned systems and uncertainty about their precise role in the field. As the indispensible contribution of unmanned systems became clear, the DoD published the first *Integrated Unmanned Systems Roadmap* in 2007 [4]. This document spanned all domains — air, ground and maritime.

That first edition identified current inventory and captured the funding for unmanned systems that spanned RDT&E, procurement, and operations and maintenance (O&M). The roadmap was updated in 2009 to include a more integrated approach. Its goal was to quantify and qualify how unmanned

systems can be optimized to support a greater set of missions, pinpointing areas of technology maturation that can be shared across all domains, and identifying technology enablers to foster collaborative operations. Some of the broader goals of this integrated roadmap were to identify opportunities for cost savings and to provide long-term strategic directions for the UAS contractor community. The roadmap continues to be updated as it evolves. The individual domains still outline their unmanned system technology requirements, but this is now done within the framework of the DoD integrated roadmap.

The Future of UAS Development

The U.S. Air Force has outlined key criteria as part of its go-forward vision for UAS [5].

- Unmanned aircraft that are fully integrated with manned aircraft across the full range of military operations
- UASs that use automated control and modular plug-and-play payloads to maximize combat capability, flexibility and efficiency
- Joint UAS solutions and teaming
- Consolidation in the number of larger platforms coupled with an increased, more tightly integrated and more flexible capability (for example, autonomy, swarming, refueling, hypersonic flight and advanced strike capabilities)

In its *Vision 2010* document, the Naval Aviation Enterprise [6] describes a range of currently used UASs that spans all five groups. As with the Air Force, the themes moving forward are consolidation, flexibility and joint operations for scalability. Two UAS programs are unique to the Navy: broad-area maritime surveillance (BAMS) and a carrier-compatible combat UAS referred to as UCAS-D. In the latter case, the D refers to a demonstration capability that may result in operational capability by 2025. UCAS-D focuses on delivering a carrier-capable combat UAS with low observability and aerial refueling technology.

The U.S. Army has described how UASs contribute to its objectives and refers to UAS as the eyes of the army [7]. Near-term UAS activities are dominated by ISR. Further out (2016 to 2025), the Army predicts that technology advances will enable greater autonomy and capability. A single operator will control multiple UASs that will team with other unmanned systems, including ground vehicles. In the long term (2026 to 2035), the Army expects significant improvements in platform commonality and capability in terms of point-to-point solutions using vertical takeoff and landing systems, all-weather operations, and wider applications such as cargo transport, medical evacuation and combat. In addition, micro-UASs will play a prominent role for rapid, tactical use during combat engagements.

When the factors from each domain are viewed in concert with the integrated roadmap, several key trends emerge:

- Transition from mission-specific platforms to a reduced number of common platforms that can serve multiple missions across domains

- Increased platform capability including all-weather flight, payload weight, speed, endurance (even ultra-endurance), point to point, survivability and refueling
- Increased payload capability that supports advanced sensing, autonomy, swarming and teaming, weaponization, and electronic warfare
- Expanded missions including strike, cargo and medical evacuation
- A reduced personnel forward footprint with a single controller guiding multiple UASs and more autonomy during landing and takeoff

The Implications for UAS Designers and Suppliers

Before reviewing the implications of these trends for UAS designers and their suppliers, it is important to consider the likely budgetary environment in which any evolution will occur.

Between 2010 and 2020, sales of UASs within the U.S. are expected to grow steadily with a compound annual growth rate (CAGR) or 3.4 percent.

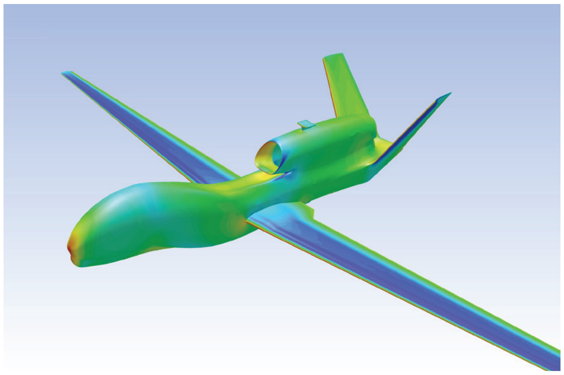
Between 2010 and 2020, sales of UASs within the U.S. — which is approximately 60 percent of global sales — are expected to grow steadily with a compound annual growth rate (CAGR) or 3.4 percent. This compares with a CAGR in the global UAS market of 2.7 percent [8]. However, beyond 2015, analysis of projected U.S. DoD spending on UASs has revealed that more will be spent on RDT&E than on procurement [2]. Ultimately, significantly more capability will be available for relatively fewer platforms, and it is likely that platform lifecycle extension demands will increase.

Even if the predicted financial landscape changes for the worse, the DoD has stated that unmanned aircraft systems will compete well, even in a fiscally constrained environment [9].

The rapidly expanding use of UASs demands equally rapid integration of new technologies into existing platforms. The speed with which missions and capabilities are being developed means design and integration cycles must be very efficient and right the first time. In an increasingly competitive environment, the companies that succeed will be able to rapidly satisfy the needs of the end user. In the near and medium term, this will require customization of products to fit a variety of platforms. In the longer term, these custom products will likely evolve into optimized, standardized, plug-and-play modules, and new capabilities will be developed to integrate in this way. This will require close co-operation and interaction between system integrators and component suppliers in a way that facilitates the design process without compromising the core intellectual property of either party.

Over the next five to 10 years, to successfully integrate advanced capabilities into existing platforms, designers and manufacturers will have to focus on size, weight and power (SWaP). Retrofitting will require a critical understanding of thermal management, shock and vibration to ensure the solution is robust and reliable.

Further out, as products and solutions mature and become standardized, it will become more important to establish levels of reliability equivalent to those of manned aircraft and to extend the system lifecycle. Reducing the personnel forward footprint will demand improvements in system aerody-



In this demonstration (and fictitious) example, ANSYS simulation software was used to improve the lift-to-drag ratio of a UAS wing over a range of angles of attack. Using goal-driven optimization, the geometry of the wing was automatically modified to achieve the desired improvement in lift. The result: a slightly modified platform that can deliver a much heavier payload.

namics and system capabilities to support more autonomous takeoff and landing.

While the fiscal pressure on UAS development may not be as great as on other military programs, the current environment is constrained, and consolidation and commonality of UAS platforms will occur across domains.

The Role of Engineering Simulation

Based on historic trends that have been observed and the UAS roadmap laid out by the major users, several key design constraints in the development of future UAS platforms and payloads can be expected:

- Very short development cycles
- Near-term design customization with little design precedent
- Medium- to long-term design optimization for standardization
- Increasingly complex missions with associated capability innovation and integration
- Tightly controlled costs and a demand for right-the- first-time design

Engineering simulation harnesses the power of computers with software that solves the fundamental equations of physics or those that are close approximations. This allows designers and analysts to create virtual representations of complete UASs and their payloads for design space analysis and optimization prior to physical testing.

Correct implementation of the technology has been verified and validated in a range of industry sectors, and the use of engineering simulation is, in some cases, mandated by regulatory bodies.

Research has shown that best-in-class companies leverage simulation to meet quality targets 91 percent of the time, compared with a 79 percent industry average.

- Aberdeen Group, 2010

The technique is well established in the aerospace and defense community, since the leading engineering simulation software companies have been in operation for over 40 years. The benefits of leveraging the technology have been proven time and again. Independent research [10] has shown that best-in-class companies:

- Meet quality targets 91 percent of the time, compared with a 79 percent industry average
- Meet cost targets 86 percent of the time, compared with a 76 percent industry average
- Launch on time 86 percent of the time, compared with a 69 percent industry average

The standout difference in strategy pursued by the best in class is the systematic use of engineering simulation regularly throughout the design process. In essence, consistently leveraging engineering simulation throughout the design process helps to drive double-digit improvements in quality, cost and time performance when compared with companies that fail to do this.

Research performed by the U.S. DoD revealed the staggering impact that engineering simulation can have [11]. A three-year study reported that

For every dollar invested in the software and computing infrastructure to support simulation, the return on investment is between $6.78 and $12.92.

U.S DOD Study

Determining the Value to the Warfighter

"for every dollar invested [in the software and computing infrastructure to support simulation], the return on investment is between $6.78 and $12.92." These are recorded returns of between 678 percent and 1,292 percent.

There is clear overlap between the quality, cost and time pressures that the UAS design and development community faces and the benefits of engineering simulation. As UAS capabilities continue to grow ever more complex for individual projects, engineering simulation will add the most value when:

- It is applied to all aspects of UAS design (requires fluid dynamics, structural mechanics, electromagnetic, thermal simulation capabilities, not just one or two in isolation)
- The interaction of the physics at a system level is included in the analysis (for example, fluid and structures for wing flutter, structures and electromagnetics for load-bearing antenna design, structural and thermal for component thermal stress analysis)
- The workflow is seamless, integrated across physics and with existing tools such as CAD and PLM
- Physics-based optimization is performed across the design envelope

At an organizational level, engineering simulation tools need to offer more than technical capability. The unique nature of UAS designs and their lack of design precedent make it critical to capture the design process and intent. That way it can be systemized and scaled for future application. Capturing and managing this engineering knowledge is best performed in the simulation tools themselves, rather than PLM systems, due to the unique nature of engineering simulation data. The ideal scenario is when the simulation tool performs the engineering knowledge management and provides the PLM system with only the right type of information as needed.

The close collaboration between OEMs and suppliers required for successful platform and payload integration demands easy exchange of engineering simulation data while mitigating mutual intellectual property and data security concerns. The engineering simulation software community has responded to these needs and, for some time now, has offered organizations the ability to manage remote repositories of simulation data and to control access rights.

Having considered the growing UAS needs of the DoD and the way the benefits of engineering simulation dovetails with these needs, it is clear that engineering simulation will be a foundational technology for the development of next-generation systems and platforms. The fit is so strong that those in the UAS community not using engineering simulation today are unlikely to be tomorrow's UAS designers or suppliers.

About Robert Harwood, Ph.D. and ANSYS, Inc.
Dr. Harwood is the Aerospace and Defense Industry Marketing Director at ANSYS. ANSYS, Inc., founded in 1970, develops and globally markets engineering simulation software and technologies widely used by engineers, designers, researchers and students across a broad spectrum of industries and academia. The company focuses on the development of open and flexible solutions that enable users to analyze designs directly on the desktop, providing a common platform for fast, efficient on the development of open and flexible solutions that enable users to analyze designs directly on the desktop, providing a common platform for fast, efficient

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